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PARAMETRIC OPTIMISATION OF WIRE EDM OF HEAT TREATED EN8 STEEL USING TAGUCHI TECHNIQUE

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ABSTRACT

The present research work optimize the parameters of wire electrical discharge machining (wire EDM) of such as pulse on, pulse off, current and voltage using the Taguchi optimization technique in machining of heat treated EN8 steel. Machining is carried out in 50mm thickness workpiece (EN8 steel) with reusable molybdenum wire electrode having diameter 180 microns. Taguchi's L18 orthogonal array with three levels was assigned for three parameters viz. pulse on time, pulse off time and current except gap voltage which is assigned to two levels because of machine limitation. Single- pass cutting was adopted to keep the aggregate machining time as low as possible. Maximum material removal rate (MRR) and average surface roughness (R_a) are accounted as response parameters. Signal to noise ratios is calculated to assess the error. It is found that current and voltage is the most dominant and influencing parameter in wire EDM of EN8 steel to achieve higher MRR or less R_a.

KEYWORDS: EN8 Steel, Heat Treatment, MRR, Surface Roughness, Taguchi & Wire EDM

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Original Article

INTRODUCTION

Wire electrical discharge machining one of the most efficient and widely accepted non-traditional machining processes in industry. Wire EDM helps to the machine on harder materials for tool and die, punches etc. with very minimal tolerances when compared to the conventional machining methods. During machining the material is removed by discrete sparks produced from the combined effect of the thermal and electrical process by a high speed traveling wire. The materials were removed by the melting and evaporation mechanism to form micro level craters. The craters were controlled by the predominant factors such as pulse in time, pulse off time, current, gap voltage and sometimes the wire tension and feed rate plays a diminutive role. EN8 steel is a medium carbon unalloyed steel preferred for gears, shafts, axle, studs, key, spindle and some general engineering components. It can be further hardened by heat treatment process. There are numerous wire electrode materials like copper, brass, zinc coated copper or brass, molybdenum etc. chosen for machining in commercial as-well-as research aspects. But molybdenum wires are best suitable for the workpiece with higher thickness like 50mm. It is less susceptible to corrosion, chemically very stable with a low coefficient of thermal expansion and melting point around 2600degree Celsius. These wires are good conductors of thermal and electrical energy which is helpful to dissipate a large amount of heat generated by the sparks rapidly and induce the sparks of high intensity. Dielectric medium (usually a liquid agent) helps to carry away the eroded materials from the craters and cool down the wire electrode

sparks and workpiece.

This research work machine the heat treated EN8 in wire EDM by varying predominant input parameters like a pulse on time, pulse off time, current and voltage with the assistance of 180 -micron diameter molybdenum wire electrode. Demineralised water with added additives improving the thermal stability, reduced vapor formation is used as the dielectric medium in this research work.

LITERATURE SURVEY

Titanium Alloys possess excellent mechanical properties, but poor machinability. Pulse on, pulse off time, peak current and servo voltage were chosen as process parameters to investigate their effects on MRR and Ra[1]. Discrete sparks induced between the tool electrode and work material facilitates machining process of wire EDM, so peak current is a dominant parameter in wire EDM [2]. There is no physical contact is established between tool and workpiece while machining, the Statistical method was used to predict the optimum machining parameters of WEDM [3]. Wire breakage occurs during machining due to improper setting [4]. Pulse interval, servo reference voltage, table speed and electrical capacitance were investigated using neural network system [5]. The experimental study was made on machining parameters; a great effort was taken and given a relationship between the variation of gap width and surface roughness with other parameters represented in the simple form [6]. Machining parameters and its outcome are examined by design of experiments [7-8]; also it reduces the cost of conducting a huge number of experiments [9-11]. Taguchi method was used to optimize the machining parameters; the effort was taken to lower kerf and increases MRR [12-14].

EXPERIMENTAL DESIGN

Selection of Orthogonal Array (OA)

The experimentation is designed on Taguchi method with three varying levels for three parameters and two levels for the fourth parameter. The levels were determined from the literature surveys and prior pilot machining of the workpiece. Table 1 shows the selected parameters and their equivalent levels. Due to the variation in the levels, a mixed level design with 18 combination sets was chosen from the available designs. In simple, L18 OA was selected and three trails of experiments were conducted for each set of parameter. The averages of three trails were taken as mean MRR and Ra.The Taguchi's L18 OA is shown in the below table 2.

Table.1: Parameter and their levels

Parameter	Level 1	Level 2	Level 3
Pulse on (μ second)	20	30	40
Pulse off (μ second)	4	8	12
Current (Ampere)	3	4	5
Voltage (Volts)	75	100	-

Table 2: Taguchi L18 Orthogonal Array Design

Experiment No.	Random No.	Pulse on (μs)	Pulse off (μs)	Current (A)	Voltage (V)
1	10	20	4	3	75
2	4	20	8	4	75
3	16	20	12	5	75
4	8	30	4	3	75
5	14	30	8	4	75
6	2	30	12	5	75
7	18	40	4	4	75

Table 2: Contd.,

8	6	40	8	5	75
9	12	40	12	3	75
10	13	20	4	5	100
11	1	20	8	3	100
12	7	20	12	4	100
13	17	30	4	4	100
14	11	30	8	5	100
15	5	30	12	3	100
16	3	40	4	5	100
17	15	40	8	3	100
18	9	40	12	4	100

SELECTION OF WORKPIECE MATERIAL

The popular and substantial medium carbon steel EN8 (Euro Norm 8) of 50mm thickness was chosen as work piece material to the machine in wire EDM with the designed experimental parameters. The untreated workpiece is subjected to heat treatment and the hardness is increased from 19 HRC to 38 HRC before the machining. The chemical composition of the EN8 steel is given in the below Table 3. The microscopic images of EN8 steel before and after heat treatment is shown in figure 1 below.

Table.3 Chemical Composition of EN8 Steel

Element	Composition (%)
Carbon	0.429
Silicon	0.278
Manganese	0.952
Phosphorus	0.041
Sulphur	0.016
Aluminium	0.023
Iron	98.26

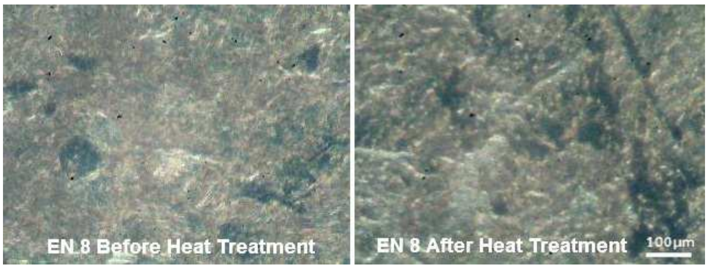

Figure 1: EN8 Steel Before and After Heat Treatment

EXPERIMENTAL SETUP

The STEER Corporation make CNC wire EDM machine is utilied in this research experimentation work. The wire EDM is equipped with computer control for parameter setting, tool path (wire electrode travel path), pressurized coolant supply system, constant and high- speed tool wire feeding system, dielectric storage pool with microfilters to screen the debris and preventing the re-entry to the coolant supply. Figure 2 shows the wire EDM setup used for machining. A single pass cut of 5x5 mm is made for each experimental machining. The typical tool path is shown in below figure 3. The experiments were carried out in the random number order given in the L18 OA table with three trials. Surface roughness is measured using MITUTOYO SJ-210-178 surface roughness tester on all sides of the machined surface and their average value is taken into account.

Figure 2: CNC Wire EDM Setup

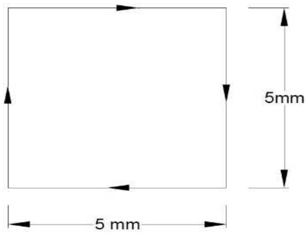

Figure 3: Wire EDM Tool Path

FORMULA USED

The below formulas are used to calculate the MRR and Signal to Noise ratios.

Maximum material removal rate can be found by multiplying the cutting velocity (Vc) in mm/sec, kerf width (b) in mm and height of the workpiece (h) in mm. Here only the cutting velocity changes for each unique set of the input parameter, whereas the kerf width and workpiece height remain unchanged.

$$\mathrm{MRR} = \mathrm{Vc} \ \mathrm{X} \ \mathrm{b} \ \mathrm{X} \ \mathrm{h} \tag{1}$$

Any factors that can be controlled are called as control factors and the rest are uncontrolled factors (noise factors). Signal to Noise ratio helps to ascertain control factors that minimize the unevenness by reducing the effect of noise factors. Noise factors can be controlled during experimentation but not during machining. In simple the variation in response related to nominal value under different noise conditions. The two types of S-N ratio used are,

The formula for Signal to Noise (S-N) ratio is,

Larger-is-Better (For MRR)

$$\eta = -10 \log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right] \tag{2}$$

Smaller-is-Better (For Ra)

$$\eta = -10 \log\left[\frac{1}{n}\sum Y_i^2\right] \tag{3}$$

EXPERIMENTAL RESULT AND DISCUSSIONS

The mean values of MRR for three trails in each input parameter set is calculated and tabulated in the below table 4 along with the corresponding signal to noise ratio. From the tabulated values of MRR, we can understand the maximum value is at the 16th set of a parameter that corresponds to pulse on time 40 µs, pulse off time 4 µs, current 5 amperes and

voltage 100 volts. The minimum value is in the 9th parameter set which corresponds to pulse on time 40 µs, pulse off time 12 µs, current 3 amperes and voltage 75 volts.

Table.4: Experimental MRR and Signal to Noise Ratio (SNR)

Experiment No.	Random No.	Mean MRR (mm3/sec)	SNR MRR
1	10	7.991	18.052
2	4	8.8206	18.91
3	16	10.4801	20.4073
4	8	8.577	18.6667
5	14	9.4331	19.4931
6	2	10.4981	20.4222
7	18	12.8262	22.162
8	6	13.0765	22.3298
9	12	6.4275	16.1608
10	13	19.1953	25.6639
11	1	10.3998	20.3405
12	7	11.5167	21.2266
13	17	16.7009	24.4548
14	11	16.9582	24.5876
15	5	9.1548	19.233
16	3	21.6472	26.708
17	15	13.1714	22.3926
18	9	13.8925	22.8556

The clear view of the wire EDM cut workpiece is shown in figure 4 and figure 5 shows the workpiece of a single trial. The figure 6 and figure 7 shows the raw data plot and Signal to Noise ratio plot for MRR respectively. To achieve the higher material removal rate one can choose the 16th set of an input parameter.

Figure 4: EN8 50mm Wire EDM Cut Work Piece

Figure 5: Trial set of 18 Wire EDM Cut Work Pieces

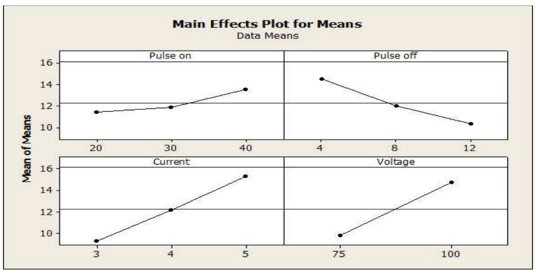

Figure 6: Raw Data Plot for Mean MRR

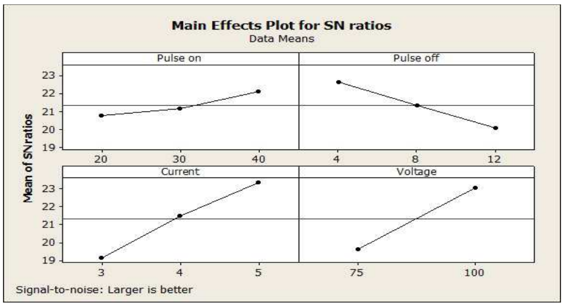

Figure.7: Signal to Noise Ratio Plot for Mean MRR

Table 5: Delta & Rank for Mean MRR

Parameter	Pulse on	Pulse off	Current	Voltage
Delta	2.106	4.161	6.022	4.945
Rank	4	3	1	2

The delta values in the above Table 5 shows current is the most substantial parameter, followed by voltage, pulse off and pulse on for achieving maximum material removal rate. Figure 8 below shows the surface roughness tester measuring the Ra of the machined workpiece.

Figure 8: Surface Roughness Measurement of Work Piece

Mean values of the average roughness on the machined surface were tabulated in the below table 6. The lesser roughness was found in the 11th set of parameter which corresponds to pulse on time 20 µs, pulse off time 8 µs, current 3 ampere and voltage 100 volts while higher roughness was found in the 8th set of parameter which corresponds to pulse on time 40 µs, pulse off time 8 µs, current 5 amperes and voltage 75 volts. Choosing the 11th set of input parameter gives lesser surface roughness on the machined surface while wiring EDM the EN8 steel.

Table 6: Experimental Ra and Signal to Noise Ratio (SNR)

Experiment No.	Random No.	Mean Ra (µm)	SNR Ra
1	10	4.495	-13.0546
2	4	4.842	-13.7005
3	16	5.267	-14.4313
4	8	4.498	-13.0604
5	14	5.116	-14.1786
6	2	5.5548	-14.8934
7	18	5.5058	-14.8164
8	6	6.0788	-15.6764
9	12	5.099	-14.1497
10	13	4.2855	-12.64
11	1	3.688	-11.3358
12	7	4.0953	-12.2457
13	17	4.5925	-13.241

Table 6: Contd.,

14	11	4.9785	-13.942
15	5	4.1833	-12.4304
16	3	5.1858	-14.2963
17	15	4.0093	-12.0614
18	9	4.943	-13.8798

The raw data plot and Signal to Noise ratio plot for Ra were portrayed in figure 9 and figure 10 respectively.

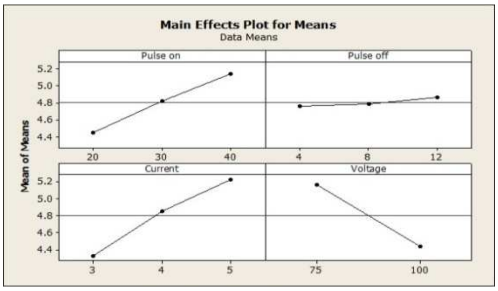

Figure 9: Raw Data Plot for Mean Ra

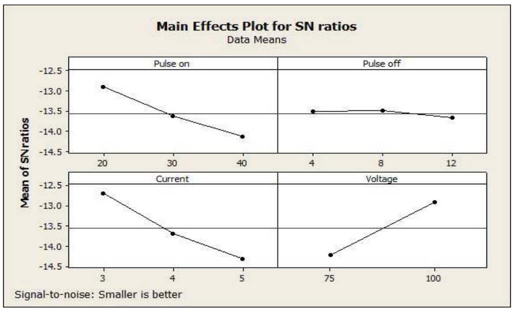

Figure 10: Signal to Noise Ratio Plot for Mean Ra

The delta values for surface roughness shown in Table 7 below depicts current is the most substantial among the other input parameters which are followed by voltage, pulse on and pulse off. The variation of delta values between the MRR and Ra is the change in the rank order of pulse on and pulse off. The pulse on gets more rank than pulse off because the material removed during pulse on time influences the roughness of the machined surface.

Table 7: Delta & Rank for Mean Ra

Parameter	Pulse on	Pulse off	Current	Voltage
Delta	0.691	0.097	0.896	0.722
Rank	3	4	1	2

Combined objective function helps to identify the combinational parameter which balances the given input equally. From the below table 8 showing values of ZMIN, it is clear that the 10th value is very least when compared with other values. So the corresponding parameters are the pulse on time 20 µs, pulse off time 4 µs, current 5 amperes and voltage 100 volts. By machining the EN8 steel with this parameter, a balanced level of maximum material removal rate and minimum surface roughness can be achieved.

Formula for combined objective function (Minimisation),

$$Z = (0.5)\ X\left(\frac{\mathrm{Ra}}{\mathrm{RaMax}}\right) - (0.5)\ X\left(\frac{\mathrm{MRR}}{\mathrm{MRR\ Max}}\right) \quad (4)$$

Table 8: Combined Objective Function (Minimisation)

Experiment No.	Mean MRR	Mean Ra	Combined Objective Function (ZMIN)
1	7.9910	4.4950	0.14597
2	8.8206	4.8420	0.1523204
3	10.4801	5.2670	0.1452448
4	8.5770	4.4980	0.1326522
5	9.4331	5.1160	0.158322
6	10.4981	5.5548	0.1659908
7	12.8262	5.5058	0.1086211
8	13.0765	6.0788	0.1449729
9	6.4275	5.0990	0.2264854
10	19.1953	4.2855	-0.1281992
11	10.3998	3.6880	0.0309963
12	11.5167	4.0953	0.0351504
13	16.7009	4.5925	-0.0480183
14	16.9582	4.9785	-0.0255782
15	9.1548	4.1833	0.0961683
16	21.6472	5.1858	-0.1186265
17	13.1714	4.0093	-0.0093879
18	13.8925	4.9430	0.0426129

A confirmation test was done using the optimal parameter set resulting from combined objective function to support the experimental results obtained and the variation were found to be less and within the acceptable limits. The below table 9 compares the experimental and confirmation test values of MRR and Ra.

Table 9: Comparison of Experimental & Confirmation Test Values

Response Parameter	Experimental Value	Confirmation Test Value	Variation %
MRR (mm3/sec)	19.1953	17.9275	6.6
Ra (µm)	4.2855	4.1286	3.66

CONCLUSIONS

EN8 steel of thickness 50mm was machined effectively in wire EDM by varying the four predominant parameters namely pulse on, pulse off, current and voltage. Taguchi's L18 OA was chosen for experimentation with three trails and the responses were carefully noted. The higher levels of pulse on, current, voltage and lower level of pulse off contributes to the maximum material removal rate. Minimum surface roughness is contributed by lower levels of a pulse on, current and moderate level of the pulse off time. From the results, it is evident that a single set of the parameter cannot give the maximum material removal rate and lesser surface roughness. But a combined objective function can be used effectively to derive a set of parameter balancing both the material removal rate and roughness of the surface. The delta value strongly shows the current as dominant parameter followed by a voltage on the influence of both the material removal rate and surface roughness. The maximum material removal rate achieved is 21.6472 mm3/sec and minimum surface roughness is 3.6880µm. A confirmation test was carried out with the optimal parameter sets and compared the same with the experimental results. It was found that the deviation is around 4-7%.

REFERENCES

1. *A V S Ram Prasad, KonnaRamji, G L Datta, An Experimental study of wire EDM on Ti-6Al-4V Alloy, Procedia Material science, Vol. 5, pp 2567-2576, 2014*

2. *M S Shanmugam, S Sai Kumar, I K Kaul, Fuzzy logic modeling of wire-cut EDM process, Proceedings of SPIE, Vol., 4192, pp 185, 2000.*
3. *N Tosun, C Cogan, G Tosun, A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method, Journal of Materials Processing Technology, Vol. 152, pp 316-322*
4. *J T Huang, Y S Liao, H C Su, A study on the machining parameters optimization of wire electrical discharge machining, Journal of Materials processing Technology, Vol. 71, pp 487-493, 1997*
5. *Debashis Dey et al., Optimization of the Tool Parameters in Ultrasonic Vibration Assisted Drilling by Taguchi Method, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Volume 6, Issue 2,March- April 2016, pp. 1-10*
6. *Y S Tarng, S C Ma, L K Chung, Determination of optimal cutting parameters in wire electrical discharge machining, International Journal of Machine Tools and Manufacture, vol. 35, pp 1693–1701, 1995.*
7. *Y S Liao, J T Huang, H C Su, A study on the machining-parameters optimization of wire electrical discharge machining, Journal of Materials Processing Technology, Vol. 71, pp 487–493, 1997.*
8. *M S Chua, M Rahman, Y S Wong, H T Loh, Determination of optimal cutting conditions using design of experiments and optimization techniques, International Journal of Machine Tools and Manufacture, vol. 33, pp 297–305, 1993*
9. *S H Lee, S H Lee, Optimization of cutting parameters for burr minimization in face-milling operations, International Journal of Production Research, vol. 41, pp 497–511, 2003*
10. *R Shanmuga Prakash, M Sivakumar, M Jeevaraja, G Saravanan, Review on Wire Electrical Discharge Machining of Die and Tool Grade Steels, International Journal of Applied Engineering Research, Vol. 10, pp521-525, 2015*
11. *W H Yang, Y S Tarng, Design optimization of cutting parameters for turning operations based on the Taguchi method, Journal of Materials Processing Technology, vol. 84, pp 122–129, 1998*
12. *T R Lin, Optimization technique for face milling stainless steel with multiple performance characteristics, The International Journal of Advanced Manufacturing Technology, vol. 19, pp 330–335, 2002*
13. *P J Ross, Taguchi Techniques for Quality Engineering, 2nd ed., McGraw-Hill, New York, USA, 1996.*
14. *S Nandhakumar, B Sivaraman, K Christal, Optimization of Wed Machining Parameters during Machining of Al SiC using RSM, Pakistan Journal of Biotechnology, Vol. 14, pp 12-15 2017*
15. *M Siva Kumar, K Sivakumar, R Shanmuga Prakash, S Vignesh, Parameters Optimisation of Wire Electrical Discharge Machining on AISI D3 Steel with Different Thickness, International Journal of Applied Engineering Research, Vol. 10, pp 185-1912, 2015*